END OF CONTRACT REPORT

LONG WAVELENGTH SEMICONDUCTOR LASERS DEVELOPMENT FOR INFRARED HETERODYNE APPLICATIONS

CONTRACT NAS5-33023

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Introduction

This report will summarize the last six months effort aimed at developing molecular beam epitaxy (MBE) grown buried heterostructure (BH) lasers operating in a continuous wave mode up to emission wavelength of 18 μm , for use in infrared heterodyne spectroscopy. In general the program was aimed towards producing high quality PbSnTe double heterostructure lasers which require advanced stripe geometry technology. The assumption was that once we will master the technology to make more simple broad area devices we will be able to apply the knowledge we gained in striping LPE grown PbSnSeTe lasers to MBE grown PbSnTe lasers. This assumption was indeed valid and the technology transfer was quick which led us to believe that it will benefit us even more when if we will implement the more recently developed buried heterostructure technology in the production of PbSnTe lasers. This technology has been proven to be superior to regular stripe geometry both in yields and performance. Manufacturing yields of buried heterostructure lasers can be compared with broad area devices. Unfortunately the major obstacle in completing the program is due to the inherent properties of the grown epilayers rather than difficulties arising from microfabricating the devices. This will be explained in detail in the following sections.

PbSnTe/PbEuSeTe BH laser performance

Originally the planned effort included the successful development of broad area diode lasers over the desired spectral range followed by the development of stripe geometry technology. After reaching a PbSnTe composition that produced 9.9 μm emission at 20 K for broad area devices, we have concluded that time constraints arising from the six month target date of the contract , dictate that a parallel effort in stripe geometry technology must be made. This effort resulted in improved stripe geometry lasers with 20 μm wide stripes and 121 K operating temperature as reported previously in detail. At that time we also attempted buried heterostructure (BH) PbSnTe lasers with PbEuSeTe cladding layers. As a result of of the fact that our diode laser product line is based on the buried heterostructure technology we did not experience any difficulty in implementing this technique to

PbSnTe compounds. After conducting more feasibility studies we concluded that it was more efficient to conduct the rest of the R&D program utilizing buried heterostructure technology. This decision was based on high yields (that even matched broad area device fabrication) and superior performance of buried heterostructure lasers. In the next phase of the research longer wavelength BH diode lasers were fabricated with laser emission reaching 13.2 µm at 20 K and cw operating temperature for certain BH lasers going as high as 175 K which is a record operating temperature for PbSnTe compounds. Detailed information regarding these results can be found in the second bi-monthly report.

Extending laser operation into longer wavelength emission

When attempting expansion of PbSnTe laser fabrication to compositions capable of emission in longer wavelengths we have noticed a degradation in the maximum operating temperatures as well as increase in threshold currents when the Sn concentration of the PbSnTe active layer was increased. When looking for a possible explanation for this phenomenon we have found that as Sn composition in undoped PbSnTe epilayers is increased, the hole concentration also increases, which creates unfavorable condition for carrier confinement. A possible solution, though not necessarily the best one, is to externally dope the active layer with an n-type dopant. Actually in order to control precisely the doping level one has to know the dependence of the carrier concentration on the dopant flux for each PbSnTe composition to be used for an active layer. This basically means many calibration runs which the time frame of the present contract would not allow. For an interim solution we have decided to dope the last third of the p-type active layer during growth, to the same level we normally dope our second cladding layer using our Bi_2Te_3 source. First we have checked the viability of this solution by growing and preparing lasers with compositions that had previous success in laser production without the need of active layer doping. Following the successful production of such lasers we have manufactured a few devices where we increased the Sn content slightly above 18 at.%. The outcome was positive with laser emission at 20 K reaching 13.4 µm. Due to the short time left on the present contract, our next few attempts concentrated on BH lasers with a $Pb_{0.78}Sn_{0.22}Te$ active layer calculated for 17 µm emission at 20 K. We have found that when injected with high currents (about 2 A) these devices lased but with wavelength corresponding to the cladding layer composition.

This means that when comparing the active and the "parasitic" junctions (the junctions between the cladding layers in a BH configuration)the efficiency of the cladding-cladding junction relative to the active layer junction was higher.

Current status of the research

The above phenomena poses a major obstacle to achieve 17 µm emitting lasers and is difficult to overcome without in depth studies of the doping properties. Therefore we are now in the process of evaluating the ties between growth conditions and the active layer' s carrier concentration. The carrier concentration of undoped PbSnTe layers is known to depend on the excess of Te in the lattice. Therefore in MBE growth of such epilayers one grows p-type layers by using a Te molecular flux in addition to the PbTe and PbSnTe sources. Without the Te molecular flux the PbSnTe layers grow n-type. We have started the following investigation. PbSnTe (22 at.% Sn) layers have been grown on BaF_2 substrates with different fluxes of Te. The appropriate carrier concentrations will be determined soon using Hall Effect measurements. If we find out that the desired hole concentration can be achieved by adjusting the Te flux, we will certainly explor this. In case we find out that external dopants have to be used to control the carrier concentrations, we will use doping of the active layer to grow lasers emitting at 17 µm.

Summary and conclusions

During the six month of the contract period we developed MBE grown PbSnTe active layer diode lasers capable to emit up to 13.4 µm. High quality stripe geometry lasers were produced with improved modal behavior. Towards the end of the contract period we have developed the BH technology for these lasers. The BH lasers showed superior optical and electrical properties in comparison with the standard stripe geometry as was expected due to better optical and electrical confinement inherent to this structure. We have not been able to reach the desired 17 μm wavelength most likely due to the high carrier concentration of the undoped PbSnTe active layers. Studies aimed to overcome this obstacle have been started.

Recommendation for future work

A. Complete studies associated with controlling active layer carrier concentration.

B. Continue MBE laser runs increasing Sn content in the active layer.

C. Repeat successful runs with lattice matched cladding layers.

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16. Abstract

Buried Heterostructure (BH) PbSnTe/PbEuSeTe MBE lasers have been fabricated. Sn concentration in the PbSnTe active layer of the PbSbTe/PbEuSeTe MBE grown BH lasers was gradually increased and devices containing 18.5 atomics % Sn were fabricated. The longest wavelength laser emission recorded so far is 13.4 pm at heat sink temperature of 20° K. Further investigation has been recommended.

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